Open and new requirements - HEP Intensity and Cosmic Frontier experiments

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Outline

- Selected aspects of experiments' Geant4 usage
- Requirements currently in Geant4 Jira system
- Other requests

Thanks to all who provided input (directly or indirectly):

- R. Bernstein, R. Fatemi, T. Fruth, R. Hatcher, T. Junk, M. Kelsey, R. Kutschke, K. Mahn, Z. Pavlovic, H. Wenzel, D. Wright, T. Yang and others

Geant4 Usage by Intensity Frontier Experiments

- DUNE subgroups and some other experiments which use LArSoft use Geant4 10.6.p01 and QGSP_BERT physics list (the beam subgroup uses Geant4 10.3.p03)
  - Compile with gcc 9.3.0, (also clang 7.0.0) and use C++17
  - Use Scientific Linux (SL) SL7, run in sequential mode
- Mu2e uses Geant4 10.7.p02 with ShieldingM physics list running in sequential or MT mode
- NOvA uses Geant4 10.4.p02 (with a patch for the density effect correction for the ionization loss), with QGSP_BERT_HP physics list
- Muon g-2 uses Geant4 10.3.p03 (with a patch correcting a spin tracking aspect), FTFP_BERT physics list, VecGeom and CADMesh for parts of the geometry (https://github.com/christopherpoole/CADMesh)
- T2K uses Geant4 10.1.p03 with QGSP_BERT_EMZ physics list running in sequential mode; Overrides the pion interaction model using the NEUT pion "cascade" model, to manage the pion secondary interaction systematics (Uses gcc 4.8 & 4.9 and C++11 as supported by gcc 4.8)
- Some experiments use containers, mainly Docker, some use Singularity, which is also used by computing grids
- Liquid Argon experiments have an option to use NEST (http://nest.physics.ucdavis.edu) when not using simpler algorithms applied after Geant4 stage
- If optical processes are needed, experiments usually pregenerate and use lookup tables to simulate photon effects due to high CPU cost of those calculations; Interested in using Opticks https://doi.org/10.1051/epjconf/201921402027 (and/or AI techniques)

Geant4 Usage by Dark Matter Search Experiments

- LZ (LUX-ZEPLIN)
  - Uses Geant4 10.3.p02 with custom physics list which includes G4EmLivermorePhysics, G4EmExtraPhysics, G4RadioactiveDecayPhysics, QGSP_BIC_HP with some internal modifications for the Gd neutron capture, G4Cerenkov, optical processes, plus additional internal physics list to simulate the liquid xenon response using the NEST model
  - Uses gcc 8.2.0, C++17; Runs on CentOS7 in sequential mode
  - Currently testing with 10.6.p02 and looking at 10.7.p02 and running in MT mode
  - Working on integrating Opticks

- SuperCDMS
  - Uses Geant4 10.6.p03 (& 10.5.p01) with Shielding physics list, optical physics, G4CMP (https://github.com/kelseymh/G4CMP), have adapted G4ScreenedNuclearRecoil from TestEm8, adapted most EM energy loss modules for use with fractionally charged particles (as the Geant4 defaults do not give correct results), deactivate G4NuclearStopping to avoid incorrect Lindhard partitioning, replace G4Decay with G4RadioactiveDecay for tritium, use LEND data for the photonuclear process
  - Plan on moving to Geant4 10.7
  - Compiles with LLVM 10.0.0, gcc 6.5.0, 7.3.0, 9.3.0 (4.8.5 for 10.5.p01 builds) and uses C++11 (and some C++14); Runs on RedHat EL6 and CentOS7, MacOS 10.14.6 in sequential mode

Open or recently modified requirements in JIRA (I)

- UR-28 Anti-proton production from proton beam
  - Correct the discrepancy in anti-proton production for proton beam at about 10 GeV on various targets
    - Currently no manpower to implement it, but important, e.g., to Mu2e

- UR-48 Precise calculation of the Fermi density effect using atomic data (closed, but should probably be reopened)
  - Feature released in 10.6, based on the code submitted by M. Strait as described in his EM Working Group meeting talk: https://indico.cern.ch/event/825436
    - NOvA would like the code submitted by M. Strait to be used instead, as per https://bugzilla-geant4.kek.jp/show_bug.cgi?id=2330
  - Also see R.M. Sternheimer et al. "Density Effect For The Ionization Loss of Charged Particles in Various Substances" Atom. Data Nucl. Data Tabl. 30 (1984) 261-271

Open or recently modified requirements in JIRA (II)

- UR-49 Neutron self-shielding effect
  - Neutron flux through a material can be significantly modified when the neutron energy is in the resonance region
  - The capture process can reduce the flux at one position in a crystal creating a kind of shadow in which the downstream atoms see a different background flux (a ~10% effect)
  - Accepted as a valid requirement, currently no manpower to implement it
- UR-50 Improve simulation of gamma induced neutron background
  - Low energy gammas producing neutrons in various materials can be a significant background
    - Photo-nuclear process does not model this well below 30 MeV
      - An improved process using the G4LEND gamma models is required
  - Accepted as a valid requirement
    - In ShieldingLEND physics list since 10.4/10.5
      - Below 20 MeV
    - Careful verification of code aspects in various areas needed

- For the list of all requirements please see:
  - https://jira-geant4.kek.jp/projects/UR

New(er) requests

- DUNE is interested in
  - a(n external) decayer handling taus (including the polarization aspect)
  - charm production (and decays, in order to model the tau neutrino component of the beam)
  - propagation of polarized muons and taus in dense media
  - in the pion inelastic process (in pi-Ar scattering), would like to
    - turn off intranuclear scattering (ref: https://geant4-forum.web.cern.ch/t/turn-off-intranuclear-scattering-in-pion-argon-interaction/5535)
    - turn off short range correlation
    - be able to obtain the momentum of the initial nucleon (Fermi momentum)
- Mu2e would like the pbar annihilation process to be improved, including being able to affect the nuclear destruction process at energy below 2GeV; Is observing an excess ratio of pi-/pi+ in p W reaction, when using Bertini cascade and would like that to be looked at
- Muon g-2 is interested in having a symplectic stepper
- Many experiments would like to be able to perform fast (and accurate) simulations of optical photon processes

- (See, e.g., parallel session talks by H. Wenzel & J. Yarba on integrating Opticks and Pythia8 as an external decayer, addressing some of the above requirements)

Summary

- Requirements evolve
  - Some have been addressed
  - Some became part of the working groups work plans
  - Some are on hold due to lack of manpower
  - More sophisticated use of Geant4 and more precise experiments lead to new requirements
  - User involvement in providing ideas and contributions is an important element of Geant4 code and collaboration evolution
- Many experiments would like to be able to perform fast (and accurate) simulations of optical photon processes
  - E.g., have/use Opticks integrated with Geant4
    - Some groups are actively working on it